COST EFFECTIVE ENERGY EFFICIENT SCHOOL DESIGN: EFFECTS OF INSULATION ON THE ENERGY PERFORMANCE OF MASONRY ENVELOPES

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ABSTRACT

The sustainable and energy efficient design of school buildings has been a significant focus of the design community in the past few years. This effort has culminated in a number of net zero school designs and a series of design guidelines. However, there has recently been concern voiced suggesting that some energy efficient school designs use much higher first cost building systems that may have higher maintenance costs and these systems are being questioned relative to their fire resistance and indoor environmental impact.

In response to these concerns an investigation was conducted with the goal of developing a list of low life cycle cost systems that can be used for energy efficient school designs in Kentucky (Climate Zone 4). Each of the systems was incorporated into a typical prototype middle school configuration and the effect each system has on the overall energy used over the life cycle of the building was determined using the eQuest analysis program, for five typical Kentucky climates. Conventional materials and construction practices were used where feasible and differential costs were developed for each system variation. These costs were used to determine simple payback periods for each system improvement.

This paper will describe results of this study, one of which suggests that increasing the thermal resistance (R) of walls much beyond the code minimum values did not significantly decrease the yearly energy use in typical school building and result in very high payback periods. Much higher decreases in energy use can be obtained with improvement in HVAC systems and controls, with lower payback periods. These results also appear to be consistent in other climate zones as well.

KEYWORDS: masonry walls, energy, efficiency, costs

INTRODUCTION

Significant effort has been focused on the sustainable and energy efficient design of school buildings over the past few years. This effort has culminated in a number of design guidelines such as Leadership in Energy and Environmental Design for Schools-New Construction and Major Renovations [1], the Kentucky Green and Healthy Schools Design Guidelines [2] and the American Society of Heating Refrigeration and Air-Conditioning Engineers ASHRAE Advanced Energy Design Guide for K- 12 Buildings [3]. These design provisions go a long way in providing guidance to design professionals and school officials on what areas in the facility design might be addressed to improve the performance of the facility. However, there appears to be a reluctance to embrace these “Green” or “Energy Efficient” designs, partially due to the perception that these designs will cost a lot more than traditional systems. For instance, we typically build schools with concrete and brick masonry walls. This is done since the masonry is relatively low cost, durable and easy to maintain. Recent developments in energy efficient school design has been moving schools to the use of higher first cost building systems that may have higher maintenance costs. This steady increase in the initial cost of schools has many school systems asking which energy conservation measures provide the best return on investments, especially in light of dwindling state budgets. They want to know where they can get the “best bang for their buck”. To answer this question, an investigation was undertaken.

The following paper briefly summarizes an investigation designed to at least partially answer this question. Due to paper size restrictions, this paper will focus primarily on the effects of envelope system variations on the energy used by a typical school building in the range of climates in Kentucky.

INVESTIGATION

To answer which systems have the greatest effect on building energy use, a prototype school design was developed. This prototype was developed based on a design published on the School Design Clearing house web site developed by the North Carolina School Planning Section of the North Carolina Department of Public Instruction [4]. This clearing house was developed to assist North Carolina school districts, architects and designers in the planning and design of high quality schools and is one of a number of its type. The prototype school design was selected so that it had both single story and two story sections and incorporated aspects typical of high school and elementary schools as well. The 14,679 m^2 (158,000 ft^2) prototype design was then modified to serve as the baseline school design. Figures 1 through 3 describe the building.

As is typical of school construction in Kentucky an exterior brick block masonry cavity wall system was used for the baseline school design. To provide the minimum base line allowed by code at the time of the investigation, the baseline building was designed to the prescriptive requirements described in the ASHRAE 90.1 ANSI/ASHRAE/IESNA Standard 90.1-2004 Energy Standards for Buildings; Except Low-Rise Residential Buildings [5]. It should be noted that the ASHRAE standard is listed as one of the design alternatives allowed by the energy code (IECC) referenced by the International Building code [6], [7] and the prescriptive provisions in both documents are similar.

To meet the prescriptive thermal properties listed in the ASHRAE standard, the exterior wall construction was assumed to consist of 4” red masonry brick, a 25 mm (1”) air space, 32 mm (1 ¼”) polystyrene rigid insulation, and a 203 mm (8”) concrete masonry unit backing wall (CMU). It was also assumed that all the interior walls were 203 mm (8”) hollow CMU’s, since this is quite common for school design. The sloped roof construction was assumed to consist of a standing seam metal roof system, asphalt impregnated building paper, 76 mm (3”) polyisocyanurate insulation, and steel framing at 610 mm (2’) spacing.

The flat roofing construction was assumed to be a white single ply roofing material, 76 mm (3”) polyisocyanurate insulation, and steel framing at 610 mm (2’) spacing. The ceiling was assumed to consist of lay-in acoustic tile with no batt insulation. It was also assumed that there are two types of doors, steel urethane foam core and single pane glass doors. The windows are assumed to be clear double pane operable windows with the code minimum allowed thermal transmittance (U) values.

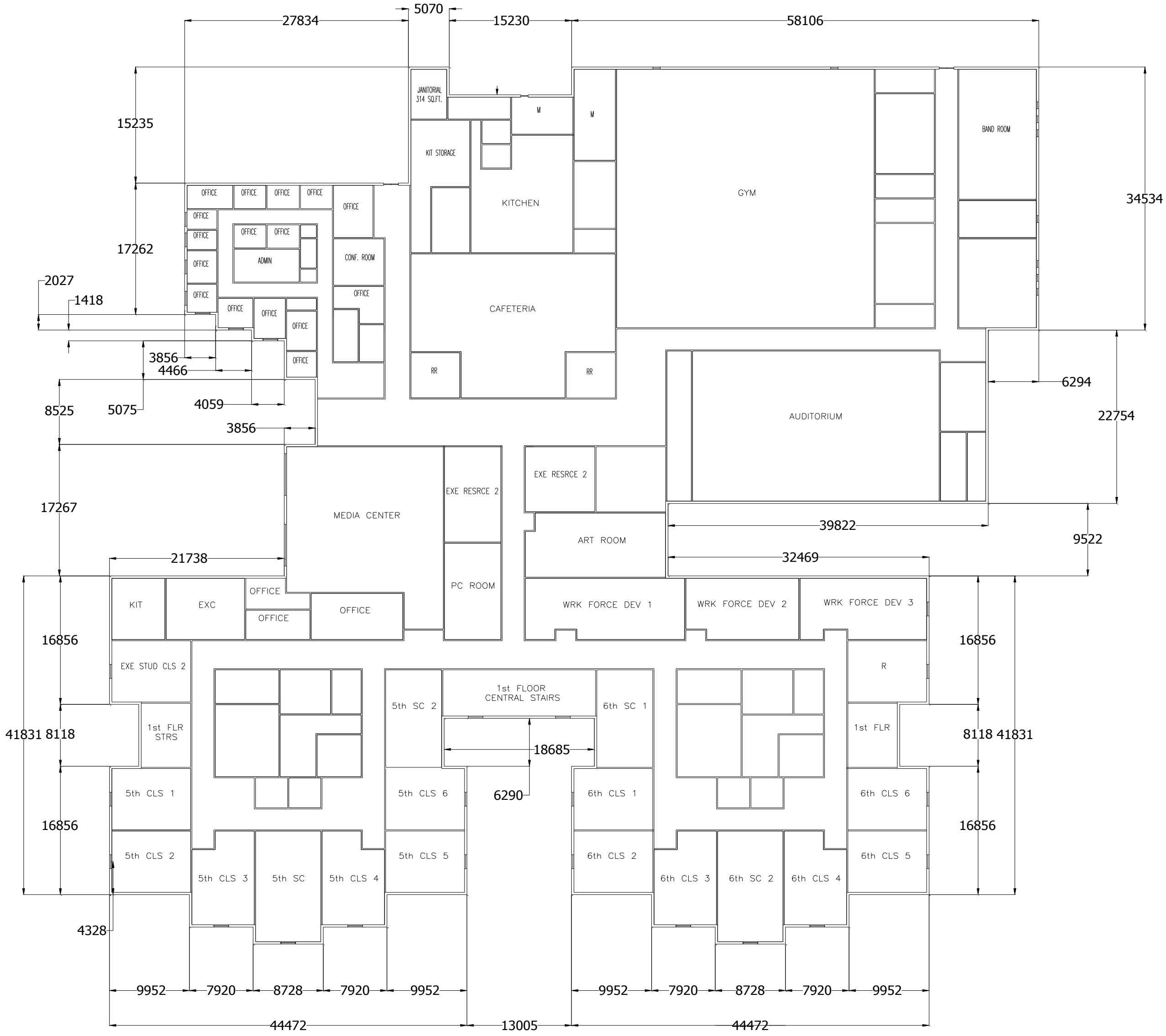


Figure 1: First Floor Plan of Baseline School

As prescribed in ASHRAE 90.1, it was assumed that the HVAC system in the baseline building was a Variable Air Volume (VAV) system, with hot water reheat at the VAV boxes. Six units were used to condition of the various zones within the building. This type of system is also capable of running on a preset thermostat set-point schedule which will reduce or increase the temperatures outside comfort levels during expected unoccupied times.

The ASHRAE 90.1 standard requires the HVAC system to support temperature set-backs. For the baseline configuration, the schedule is based on a heating temperature of 22.2°C (72°F) and a cooling temperature of 23.3°C (74°F) during the occupied times and during the unoccupied times, the heating temperature is set to 17.8°C (64°F) and the cooling temperature is set to 26.7°C (80°F).

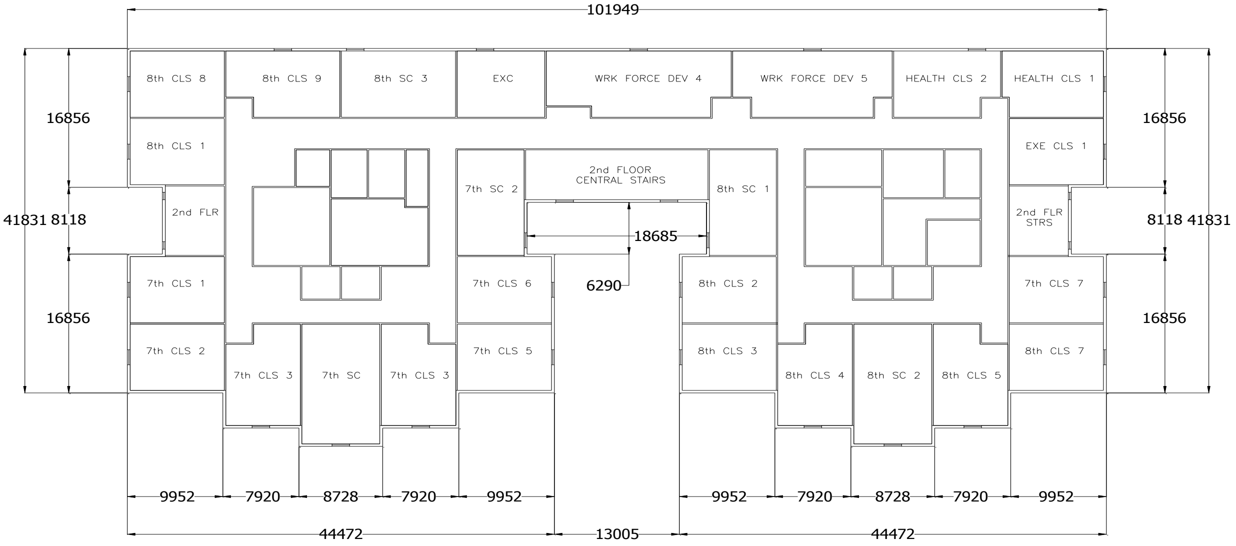
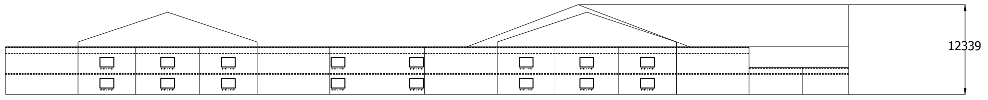
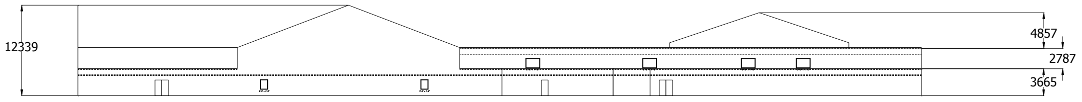


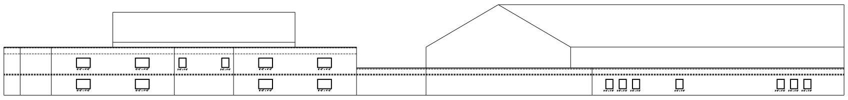
Figure 2: Second Floor Plan of Baseline School



South Elevation



North Elevation



West Elevation

Figure 3: Elevations of Baseline School

Using traditional design approaches and systems, the base HVAC system was designed and consisted of six standard variable air volume (VAV) units. Each VAV unit was assumed to have multiple VAV boxes, serving individual zones. The reheat coil at each VAV box was operated to maintain room temperature within the comfort zone. Cooling was provided by chilled water that was produced from a water cooled, electric centrifugal hermetic chiller. Heating was provided by a forced draft natural gas boiler. The baseline HVAC system controls were set up to send cooling air at 12.8 °C (55°F) to each VAV box and the hot water coils in the VAV box were designed to heat up the air, if local heating is required. If cooling is required, the hot water coil valve at the VAV box is closed. This operation allows simultaneous heating and cooling year round in different areas of the building, as it provides good comfort and has relatively low construction costs. The HVAC systems were assumed to operate 24 hours a day, 7 days a week, and occupancy was limited to week days from 8 a.m. to 3 p.m., and 9 a.m. to 2 p.m. through the summer. Economizers are installed to provide cooling when the outside air temperature is below18.3°C (65°F). Domestic hot water is provided by a 3558 litre (940 gallon) natural gas water heater.

Finally, even though most new school designs use T-8 fluorescent lighting fixtures with electronic ballasts, the main lighting systems for the baseline building were assumed to be T-12 fluorescent lamps with magnetic ballasts. This was done to allow later evaluation of the effects of more efficient lighting. Standard Watts/unit area coefficients were used to define the lighting loads for a given area type (the energy analysis software default values were used). It was also assumed that the Gym used metal halide pendant lamp systems. Typical lamp wattages were used to determine the total number of fixtures in a given area.

The energy use performance of this baseline design was analysed using the eQuest 3.64 Energy Analysis program. This program uses the DOE 2.0 analysis engine to simulate the yearly energy use in building systems using typical external weather conditions and interior loading schedules. This program was selected since it meets energy code requirements and has been used extensively for holistic energy analysis [8]. The program was used to ensure code compliance and simulate yearly energy use using hourly weather data from five Kentucky cities; Louisville, Lexington, Covington, Paducah or Corbin/Williamsburg.

The energy yearly energy use profiles were developed and the baseline yearly energy use profiles for Louisville, KY are shown in Figures 4 and 5.

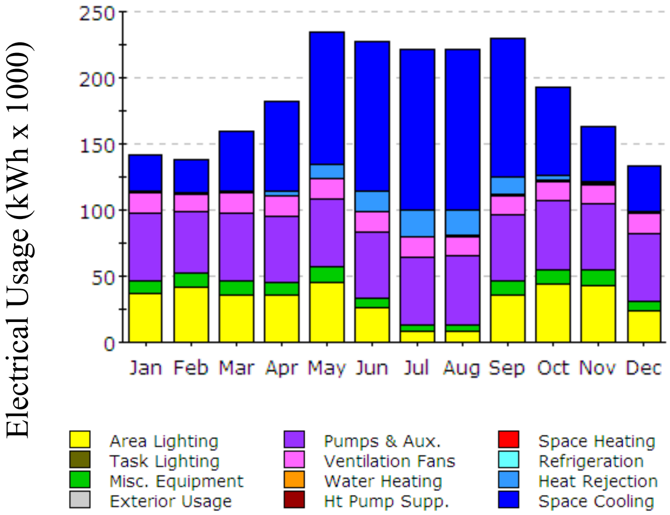


Figure 4: The Baseline Monthly Electrical Usage Profile (Louisville)

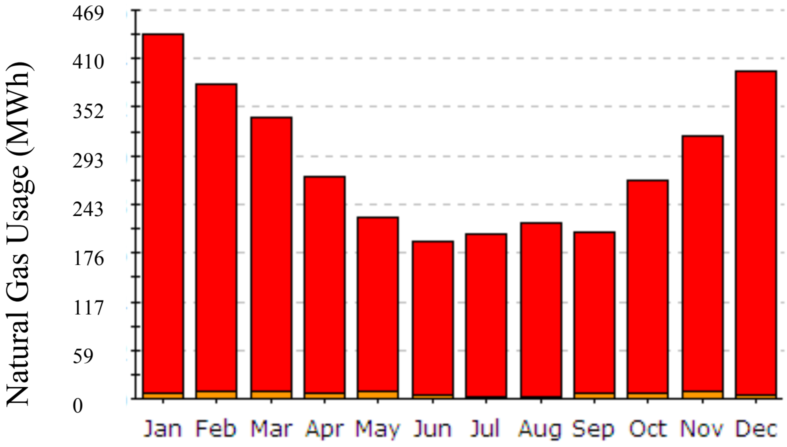


Figure 5: The Baseline Monthly Natural Gas Usage (Louisville)

The energy simulation produced a baseline annual electrical energy for Louisville of 2,253,991 kWh, with a demand of 5,622 kW. The total yearly gas energy was 3,412,899 kWh. This produced an energy use index (EUI) of 416 kWh/m^2 (132 kBtu/SF). This EUI compared quite favourably with the average yearly EUI of 533 kWh/m^2 (169 kBtu/SF) obtained from a 2003 DOE survey [9] for K-12 facilities, and suggests that the model simulation is consistent with school energy use. Similar EUI values were obtained for the other four cities ranging from 410 to 426 kWh/m^2 (130 to 135 kBtu/SF). Note the internal heated area was used in the EUI calculations.

Based on a survey of the design community, facility managers, contractors and a literature review, mature energy conservation measures (ECM's) that have, or could be applied to save energy in typical school configurations were identified. These ECM's were incorporated into the typical "prototype" middle school building configuration and the effects each system had on the yearly energy use was determined using the eQuest energy analysis program.

Some of the energy conservation measures involved improvements in the building envelope and included:

1. Increasing roof insulation from 76 mm (3"), to 102 mm (4") and then 127 mm (5") thick polyisocyanurate foam board.
2. Increasing the exterior masonry cavity wall insulation from 32 mm (1 ¼") thick polystyrene, to 38 mm (1 ½") thick polystyrene, to 51 mm (2") and then 76 mm (3") polyisocyanurate foam board.
3. Using an exterior insulated concrete form (ICF) wall system consisting of 102 mm (4") face brick, 25 mm (1") air space, 38 mm (1 ½") polyurethane, 152 mm (6") concrete, 38 mm (1 ½") polyurethane, and 13 mm (½") gypsum board.
4. Using an exterior steel stud wall system of 102 mm (4") face brick, 25 mm (1") air space, 38 mm (1 ½") thick polystyrene foam insulation board, 51 mm x 152 mm (2" x 6") steel studs spaced at 406 mm (16") on centre with R 3.35 K·m²/W (R-19 h·ft²·°F/Btu) batt insulation in between the studs, and 13 mm (½") interior gypsum board. The cavity insulation was varied but only the 89 mm (3 ½") polyisocyanurate board performance is reported in this paper since it provided the best energy performance.

7. A combination ECM configuration that included an exterior ICF wall system and 127 mm (5”) of polyisocyanurate insulation board for the roofing insulation.
8. A combination ECM configuration with an exterior masonry cavity wall system, 51 mm (2”) of polyisocyanurate cavity insulation and 127 mm (5”) of polyisocyanurate roof insulation.
9. A combination ECM configuration with an exterior masonry cavity wall system, 76 mm (3”) polyisocyanurate cavity insulation and 127 mm (5”) of polyisocyanurate roofing insulation.
10. The base exterior wall infiltration rate of 0.5 air changes per hour was changed to 0.2, 0.15 and 0.1 air changes per hour. This was done to simulate the effect of higher air tightness on energy usage.
11. The thermal transmission coefficient (U) of the windows was changed from the baseline of 3.06/3.63 W/°Km^2 (0.54/0.64 Btu/(h °F ft^2)) (code maximum), to higher conductivity windows-U values of 3.80/3.92 W/°Km^2 (0.67/.69 Btu/(h °F ft^2)), and lower conductivity windows 1.31/1.76 W/°Km^2 (0.23/.31 Btu/(h °F ft^2)).

There were also a number of HVAC system variations, lighting system variations and control system variations evaluated. Due to paper size limitations, only three of these will be described in detail in this paper. The first variation replaced the baseline VAV system with a ground source heat pump system. The second variation replaced the T-12 florescent lights with T–8 lamps and electronic ballasts and the high bay halides with high output fluorescents. The third variation increased the boiler efficiency from the 80% code minimum to 90%. Further information on the other aspects of this study can be found in a report by McGinley [10].

For each system, a design was developed and an energy simulation was conducted. Where possible the design algorithms in the software were used to assist in the system design. The energy simulations were used to generate annual energy costs. The cost of the electricity and gas were calculated using commercial utility rate structures. These costs were \$0.0748/kWh, \$12.00/kW and \$0.0341/kWh (\$0.01/kBtu) for the gas energy. The yearly energy use and costs for the each simulation in Louisville are listed in Table 1. The results in the other four cities were similar.

Each variation in building system configuration was used to compile a construction cost estimate. This analysis involved determining the incremental costs associated with changes in building configuration needed to support each ECM. These costs were generated by first estimating the quantity and configuration of the affected systems in the base building configuration. The quantity and configuration of the systems in the new building system configuration was then estimated. Unit costs for the original and modified systems were estimated for the five Kentucky cities using the RSMEANS Building Construction Cost Data Manual [11], the RSMEANS Building Mechanical Cost Data Manual [12], the RSMEANS Electrical Construction Cost Data Manual [13], input from a certified construction estimator, and input from mechanical contractors and HVAC engineers familiar with the design and construction of the systems being evaluated. The incremental system costs were then determined for each ECM by simply subtracting the new system cost from the base configuration. Note that the incremental wall costs did not account for additional costs that might be associated with larger cavity spaces that additional insulation may require. Increased cavity widths may require more expensive ties, window and door frames and shelf angle support systems. These additional costs would depend on applications and were ignored in the analysis.

Table 1: Energy Analysis and Cost Data

CM #	Description	Construction Data Notes	Quantity	Energy	Energy Cost	Cost/Payback (Years)
Baseline	Baseline	Baseline	Electric kWh	2,253,991	$ 76,320	
			Demand KW	5,622	$ 63,466	
			Gas KWh	3,410,615	$ 87,182	
			Baseline EUI kWh/m2	416	$ 226,968	$0/0
C.1	Pitched Roof R-25.64 Built Up Roof R-29.41	Change 3” exterior Polyisocyanurate to 3.5” exterior Polyisocyanurate	Electric kWh	2,253,298	$ 76,297	
			Demand KW	5,620	$ 63,448	
			Gas KWh	3,400,434	$ 86,922	
			C.1 EUI kWh/m2	416 /.2%	$226,667 / .1 %	$84,275 /255
C.2	Pitched Roof R-29.41 Built Up Roof R-33.33	Change 3” exterior Polyisocyanurate to 4” exterior Polyisocyanurate	Electric kWh	2,252,749	$ 76,278	
			Demand KW	5,619	$ 63,435	
			Gas KWh	3,392,325	$ 86,715	
			C.2 EUI kWh/m2	415 /.3%	$226,428 / .2 %	$94,679 /160
C.3	Pitched Roof R-37.04 Built Up Roof R-40.00	Change 3” exterior Polyisocyanurate to 5” exterior Polyisocyanurate	Electric kWh	2,251,926	$ 76,250	
			Demand KW	5,618	$ 63,415	
			Gas KWh	3,379,868	$ 86,397	
			C.3 EUI kWh/m2	414 /.6%	$226,061 / .4 %	$187,277 /188
C.4	ICF walls R-21.74	ICF Wall: air film, 4" brick, air space, 1.5" Polyurethane, 6" 140lb conc., 1.5" Polyurethane, 1/2" gyp board, air film	Electric kWh	2,253,728	$ 76,311	
			Demand KW	5,623	$ 63,472	
			Gas KWh	3,381,568	$ 86,440	
			C.4 EUI kWh/m2	414 /.5%	$226,224 / .3 %	$252,987 /335
C.5	CMU walls R-25	Changed 1-1/4" Polystyrene to 3" ployiso	Electric kWh	2,253,297	$ 76,297	
			Demand KW	5,621	$ 63,452	
			Gas KWh	3,378,872	$ 86,371	
			C.5 EUI kWh/m2	414 /.6%	$226,120 / .4 %	$33,032 /75
C.6	CMU walls R-18.18	Changed 1-1/4" Polystyrene to 2" ployiso	Electric kWh	2,253,456	$ 76,302	
			Demand KW	5,621	$ 63,455	
			Gas KWh	3,385,731	$ 86,546	
			C.6 EUI kWh/m2	415 /.4%	$226,304 / .3 %	$8,923 /13
C.7	CMU walls R-13.33	Changed 1-1/4" Polystyrene to 1 1/2" polyurethane	Electric kWh	2,253,659	$ 76,309	
			Demand KW	5,621	$ 63,459	
			Gas KWh	3,394,714	$ 86,776	
			C.7 EUI kWh/m2	415 /.3%	$226,544 / .2 %	No Cost ECM
C.8	Steel Stud Walls R-34.5	Steel wall stud layers: air film, 4" face brick, air space, 3.5" polyiso, 2x6 steel wall 16 O.C. R-19 batt insul, gypsum board air film	Electric kWh	2,253,852	$ 76,315	
			Demand KW	5,623	$ 63,475	
			Gas KWh	3,376,671	$ 86,315	
			C.8 EUI kWh/m2	414 /.6%	$226,105 / .4 %	Lower Capital Cost
C.12	10% air infiltration rate	Change all A-C air change rates to .10 air changes/hour	Electric kWh	2,254,430	$ 76,335	
			Demand KW	5,623	$ 63,478	
			Gas KWh	3,415,880	$ 87,317	
			C.12 EUI kWh/m2	417 /-.1%	$227,130 / -.1 %	NO RETURN
C.13	15% air infiltration rate	Change all A-C air change rates to .15 air changes/hour	Electric kWh	2,250,902	$ 76,216	
			Demand KW	5,614	$ 63,375	
			Gas KWh	3,394,901	$ 86,781	
			C.13 EUI kWh/m2	415 /.3%	$226,372 / .3 %	$42,385 /60
C.14	20% air infiltration rate	Change all A-C air change rates to .20 air changes/hour	Electric kWh	2,247,549	$ 76,102	
			Demand KW	5,606	$ 63,278	
			Gas KWh	3,375,504	$ 86,285	
			C.14 EUI kWh/m2	413 /.7%	$225,664 / .6 %	$84,770 /45
C.15	ICF R-21.74, Pitched Roof R-37.04 Built Up Roof R-40.00	Wall: air film, 4" brick, air space, 1.5" Polyurethane, 6" 140lb conc., 1.5" Polyurethane, 1/2" gyp board, air film; for roof: Changed 3”	Electric kWh	2,251,740	$ 76,244	
			Demand KW	5,618	$ 63,421	
			Gas KWh	3,358,227	$ 85,843	
			C.15 EUI kWh/m2	412 /1.0%	$225,509 / .6 %	$440,264 /283
C.16	CMU walls R-18.18 Pitched Roof R-37.04 Built Up Roof R-40.00	for wall Changed 1-1/4" Polystyrene to 2" polyiso, for roof Changed 3” exterior Polyisocyanurate to 5” exterior Polyisocyanurate	Electric kWh	2,253,024	$ 76,287	
			Demand KW	5,620	$ 63,446	
			Gas KWh	3,368,961	$ 86,118	
			C.16 EUI kWh/m2	413 /.8%	$225,851 / .5 %	$196,200/169
C.17	CMU walls R-25 Pitched Roof R-37.04 Built Up Roof R-40.00	for wall Changed 1-1/4" Polystyrene to 3" ployiso, for roof Changed 3” exterior Polyisocyanurate to 5” exterior Polyisocyanurate	Electric kWh	2,251,232	$ 76,227	
			Demand KW	5,617	$ 63,401	
			Gas KWh	3,348,481	$ 85,594	
			C.17 EUI kWh/m2	412 /1.1%	$225,222 / .8 %	$253,309 /136
C.18	Window Option 1	Higher U value	Electric kWh	2,253,741	$ 76,312	
			Demand KW	5,621	$ 63,460	
			Gas KWh	3,411,654	$ 87,209	
			C.18 EUI kWh/m2	417 /.0%	$226,981 / .0 %	Lower Capital Cost
C.19	Window Option 2	Lower U value	Electric kWh	2,253,076	$ 76,289	
			Demand KW	5,620	$ 63,447	
			Gas KWh	3,397,875	$ 86,857	

Table 1 (cont.): Energy Analysis and Cost Data

CM #	Description	Construction Data Notes	Quantity	Energy	Energy Cost	Cost/Payback (Years)
L.1	T8 Lighting	Change all building lights from T12 to T8,Change ballast from Energy Efficient Magnetic to Rapid Start Electronic	Electric kWh	2,136,992	$ 72,359	
			Demand KW	5,108	$ 57,792	
			Gas KWh	3,534,076	$ 90,338	
			L.1 EUI kWh/m2	417 /-.1%	$220,488 / 2.9 %	No Cost ECM
M.1	90% Boiler Efficiency		Electric kWh	2,253,991	$ 76,320	
			Demand KW	5,622	$ 63,466	
			Gas KWh	3,039,941	$ 77,707	
			M.1 EUI kWh/m2	389 /6.5%	$217,493 / 4.2 %	$2,265/0.2
G.M.17	Geothermal Heat Pump System	Change HVAC System from VAV to Geothermal	Electric kWh	1,518,665	$ 51,422	
			Demand KW	6,085	$ 67,864	
			Gas KWh	74,009	$ 1,892	
			G.M.17 EUI kWh/m2	117 /71.9%	$121,178 / 46.6 %	$3,787,000 /28

A simple payback analysis was conducted by taking the ratio of incremental capital costs and annual energy cost savings. These results are also presented in Table 1. In the investigation, a more elaborate self-funding analysis was conducted. This analysis incorporated an interest rate of 4.5%, a yearly increasing cost of energy of 1.5% and accounted for the maintenance costs of each system and determined the year when each ECM produced a net surplus. As the simple payback analysis and the self-funding analysis gave similar results, only the simple payback analysis is presented in this paper.

Examination of Table 1 indicates that, in general, improvements in the thermal resistance of the building envelope reduces yearly energy used by less than 1% and has long payback durations, most being greater than 100 years. It does appear that minor low cost improvement in the envelope improvements over code minimums can have lower paybacks but does not save significant amounts of energy. These payback periods would be even greater if the incremental costs associated with larger cavities are accounted for.

The data in Table 1 also shows that the significant energy savings is realized by changes in the mechanical systems. In fact, a yearly energy savings of 70% is realized by simply changing the HVAC system to a ground source heat pump system. Furthermore, even though these systems are much more costly, the payback period of 28 years is still much lower that most of the envelope improvements.

Finally, examination of the yearly energy performance of changing the lights from T-12 to the more efficient T-8 fluorescent systems, shows the importance of conducting holistic energy studies. Simple calculations would suggest about a 6% energy reduction for this change. However, even though the electrical energy shows a significant drop, the gas heating energy increased. This appears to be due to the fact that the T -8 lamps give off lower amounts of waste heat than the T-12 lamps. This requires greater amounts of heating energy to be provided to the space during the heating system, resulting in little overall energy use reduction with this ECM. There is however about a 3% energy cost savings, as electrical energy is more costly than gas energy.

To examine whether the insensitivity of yearly energy use to envelope improvements was specific to the Kentucky climate (ASHREA Climate Zone 4), additional analyses were conducted. The base building model was evaluated using hourly weather data from Dallas-TX (hot), Miami-FL (hot and humid) and Madison-WI (cold). Select envelope improvement ECM's were also evaluated. The yearly energy savings based on the base line building are presented in

Figure 6 for each of the ECM's. For comparison purposes the yearly energy savings for Covington-KY and Paducah-KY are also shown in Figure 6.

Evaluation of the results in Figure 6 shows that increases in envelope thermal resistances can actually increase the energy used in hot climates (Dallas and Miami). In colder climates the quantity of energy saved on a yearly basis increases compared to Kentucky climates, but is still less than 3%.

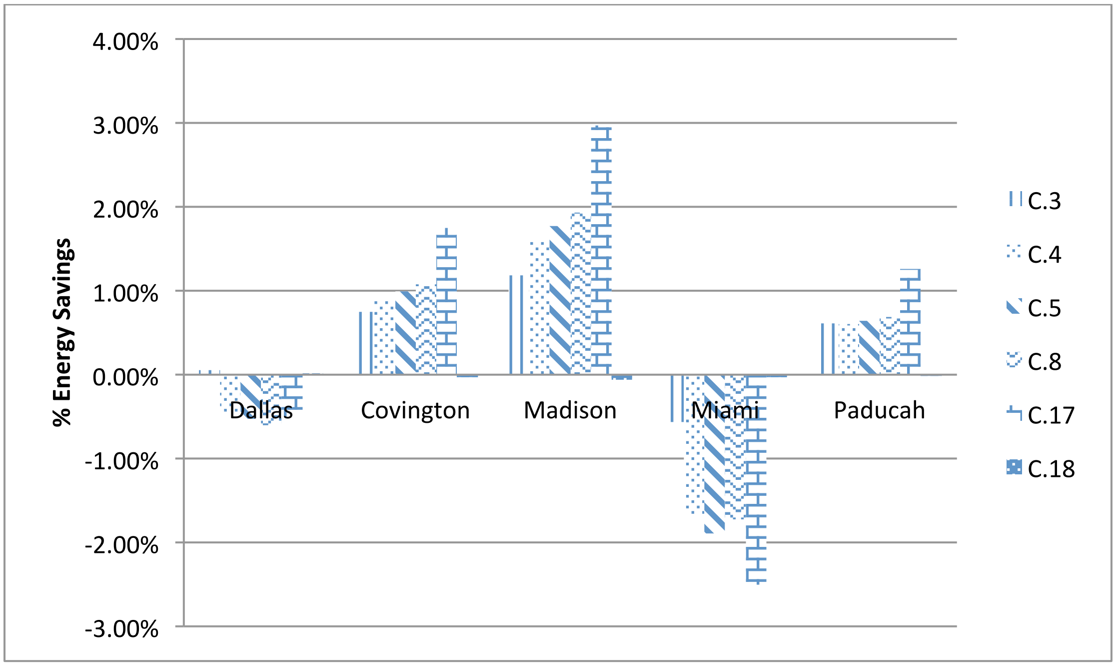


Figure 6: Yearly Energy Savings for Envelope Improvement in Various US Climates

SUMMARY AND CONCLUSIONS

An investigation was conducted with the goal of developing a list of low life cycle cost systems that can be used for energy efficient school designs in Kentucky (Climate Zone 4). Each of the systems was incorporated into a typical prototype middle school configuration and the effect each system has on the overall energy used over the life cycle of the building was determined using the eQuest analysis program, for five typical Kentucky climates. Conventional materials and construction practices where used where feasible and differential costs were developed for each system variation. These costs were used to determine simple payback periods for each system improvement.

Based on the investigation the following conclusions can be made:

1. Envelope improvements beyond code minimums in the prototype school design typically reduced the yearly energy used by less than 1.0%.
2. For the configurations studied, simple payback periods for envelope improvements are typically in excess of 100 years.
3. Large decreases in yearly energy use were produced by changes in the HVAC systems.
4. For the configurations studied, simple payback periods of HVAC changes were generally far less than those of the envelope improvements.

5. For hot climates, envelope improvements in the prototype school design typically increased the yearly energy used.
6. For colder climates, envelope improvements in the prototype school design have typically decreased the yearly energy by a larger percentage than that shown for typical Kentucky climates, but always less than 3% for the configurations evaluated by the study.

ACKNOWLEDGEMENTS

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REFERENCES

1. United States Green Building Council (2007), "LEED for Schools for New Construction and Major Renovations" USBGC, Washington, DC.
2. Kentucky Environmental Education Council (2008), "Kentucky Green Schools Design Manual", Kentucky Education Cabinet, Frankfort, KY.
3. American Society of Heating Refrigeration and Air-Conditioning Engineers (2008), Advanced Energy Design Guide for K- 12 Buildings., American Society of Heating Refrigeration and Air-Conditioning Engineers, Atlanta, GA, USA.
4. North Carolina School Planning Section of the North Carolina Department of Public Instruction, "Prototype Design Clearing House" (2008), http://www.schoolclearinghouse.org.
5. American Society of Heating Refrigeration and Air-Conditioning Engineers, "ANSI/ASHRAE/IESNA Standard 90.1 (2004 and 2007 versions) Energy Standard for Buildings Except Low-Rise Residential Buildings", American Society of Heating Refrigeration and Air-Conditioning Engineers, Atlanta, GA, USA.
6. The International Code Council (2009), International Building Code (IBC), 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001.
7. The International Code Council (2009), International Energy Conservation Code (IECC), 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001,.
8. US Department of Energy (2010), Energy Analysis programs, http://doe2.com/equest/2010.
9. US Department of Energy -Energy Star Program (2003), Energy indexes,http://www.energystar.gov/index.cfm?fuseaction=buildingcontest.eui.
10. McGinley, W. M, "Cost Effective Energy Efficient School Design", Final Report, Kentucky Renewable Energy Consortium, Frankfort, KY, July, 2011.
11. RsMEANS (2011), Building Construction Cost Data, RsMeans, Norwell MA.
12. RsMEANS (2011), Building Electrical Cost Data, RsMeans, Norwell MA.
13. RsMEANS (2011), Building Mechanical Cost Data, RsMeans, Norwell MA.